

## Chapter II: Health and Welfare Concerns

This chapter describes the public health and welfare concerns associated with the pollutants impacted by this rulemaking, including ozone, particulate matter, carbon monoxide, air toxics, and regional haze.

### A. Ozone

Ground-level ozone, the main ingredient in smog, is formed by complex chemical reactions of volatile organic compounds (VOC) and nitrogen oxides (NO<sub>x</sub>) in the presence of heat and sunlight. Ozone forms readily in the lower atmosphere, usually during hot summer weather. VOCs are emitted from a variety of sources, including motor vehicles, chemical plants, refineries, factories, consumer and commercial products, and other industrial sources. VOCs also are emitted by natural sources such as vegetation. NO<sub>x</sub> is emitted largely from motor vehicles, nonroad equipment, power plants, and other sources of combustion.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions involving NO<sub>x</sub>, VOC, heat, and sunlight.<sup>a</sup> As a result, differences in NO<sub>x</sub> and VOC emissions and weather patterns contribute to daily, seasonal, and yearly differences in ozone concentrations and differences from city to city. Many of the chemical reactions that are part of the ozone-forming cycle are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and produce more ozone than typically would occur on a single high temperature day. Further complicating matters, ozone also can be transported into an area from pollution sources found hundreds of miles upwind, resulting in elevated ozone levels even in areas with low VOC or NO<sub>x</sub> emissions.

Emissions of NO<sub>x</sub> and VOC are necessary for the formation of ozone in the lower atmosphere. For example, small amounts of NO<sub>x</sub> enable ozone to form rapidly when VOC levels are high, but ozone production is quickly limited by removal of the NO<sub>x</sub>. Under these conditions, NO<sub>x</sub> reductions are highly effective in reducing ozone while VOC reductions have little effect. Such conditions are called “NO<sub>x</sub> limited.” Because the contribution of VOC emissions from biogenic (natural) sources to local ambient ozone concentrations can be significant, even some areas where man-made VOC emissions are low can be NO<sub>x</sub> limited.

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<sup>a</sup> Carbon monoxide also participates in the production of ozone, albeit at a much slower rate than most VOC and NO<sub>x</sub> compounds.

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When NO<sub>x</sub> levels are high and VOC levels relatively low, NO<sub>x</sub> forms inorganic nitrates but little ozone. Such conditions are called "VOC limited." Under these conditions, VOC reductions are effective in reducing ozone, but NO<sub>x</sub> reductions can actually increase local ozone. The highest levels of ozone are produced when both VOC and NO<sub>x</sub> emissions are present in significant quantities.

Rural areas are almost always NO<sub>x</sub> limited, due to the relatively large amounts of biogenic VOC emissions in such areas. Urban areas can be either VOC or NO<sub>x</sub> limited, or a mixture of both, in which ozone levels exhibit moderate sensitivity to changes in either pollutant.

Ozone concentrations in an area also can be lowered by the reaction of nitric oxide with ozone, forming nitrogen dioxide (NO<sub>2</sub>); as the air moves downwind and the cycle continues, the NO<sub>2</sub> forms additional ozone. The importance of this reaction depends, in part, on the relative concentrations of NO<sub>x</sub>, VOC, and ozone, all of which change with time and location.

### **1. Health and Welfare Effects of Ozone**

Based on a large number of recent studies, EPA has identified several key health effects caused when people are exposed to levels of ozone found today in many areas of the country.<sup>1, 2</sup> Short-term exposures (1-3 hours) to high ambient ozone concentrations have been linked to increased hospital admissions and emergency room visits for respiratory problems. For example, studies conducted in the northeastern U.S. and Canada show that ozone air pollution is associated with 10-20 percent of all of the summertime respiratory-related hospital admissions. Repeated exposure to ozone can make people more susceptible to respiratory infection and lung inflammation and can aggravate preexisting respiratory diseases, such as asthma. Prolonged exposure to ozone can cause repeated inflammation of the lung, impairment of lung defense mechanisms, and irreversible changes in lung structure, which could lead to premature aging of the lungs and/or chronic respiratory illnesses such as emphysema and chronic bronchitis.

Children are most at risk from ozone exposure because they typically are active outside, playing and exercising, during the summer when ozone levels are highest. For example, summer camp studies in the eastern U.S. and southeastern Canada have reported significant reductions in lung function in children who are active outdoors. Further, children are more at risk than adults to ozone exposure because their respiratory systems are still developing. Adults who are outdoors and moderately active during the summer months, such as construction workers and other outdoor workers, also are among those most at risk. These individuals, as well as people with respiratory illnesses such as asthma, especially asthmatic children, can experience reduced lung function and increased respiratory symptoms, such as chest pain and cough, when exposed to relatively low ozone levels during periods of moderate exertion.

Several recent studies have shown a possible relationship between exposure to ambient

ozone and premature mortality. This literature has been evolving rapidly. Of the 28 time-series epidemiology studies identified in the literature that report results on a possible association between daily ozone concentrations and daily mortality<sup>3</sup>, 21 were published or presented since 1995. In particular, a series of studies published in 1995 through 1997 (after closure on the current ozone NAAQS Criteria Document) from multiple cities in western Europe has increased significantly the body of studies finding a positive association. Fifteen of the 28 studies report a statistically significant relationship between ozone and mortality; the more recent studies tended to find statistical significance more often than the earlier studies. The ozone-mortality datasets also have tended to become larger in more recent studies, as longer series of air quality monitoring data have become available over time. This suggests that it may take many years of data before the ozone effect can be separated from the daily weather and seasonal patterns with which it tends to be correlated.

In 1997, as a part of the Regulatory Impact Analysis (RIA) for the ozone NAAQS promulgation, EPA staff reviewed this recent literature. They identified nine studies that met a defined set of selection criteria, and conducted a meta-analysis of the results of the nine studies. (U.S. EPA, 1997). See Chapter VII.C.3.a. for a further discussion of this meta-analysis.

In addition to human health effects, ozone adversely affects crop yield, vegetation and forest growth, and the durability of materials. Because ground-level ozone interferes with the ability of a plant to produce and store food, plants become more susceptible to disease, insect attack, harsh weather and other environmental stresses. Ozone causes noticeable foliar damage in many crops, trees, and ornamental plants (i.e., grass, flowers, shrubs, and trees) and causes reduced growth in plants. Studies indicate that current ambient levels of ozone are responsible for damage to forests and ecosystems (including habitat for native animal species). Ozone chemically attacks elastomers (natural rubber and certain synthetic polymers), textile fibers and dyes, and, to a lesser extent, paints. For example, elastomers become brittle and crack, and dyes fade after exposure to ozone.

VOC emissions are detrimental not only for their role in forming ozone, but also for their role as air toxics. Some VOCs emitted from motor vehicles are toxic compounds. At elevated concentrations and exposures, human health effects from air toxics can range from respiratory effects to cancer. Other health impacts include neurological, developmental and reproductive effects. Chapter III contains more information about air toxics.

Besides their role as an ozone precursor, NO<sub>x</sub> emissions produce a wide variety of health and welfare effects.<sup>45</sup> These problems are caused in part by emissions of nitrogen from motor vehicles. Nitrogen dioxide can irritate the lungs and lower resistance to respiratory infection (such as influenza). NO<sub>x</sub> emissions are an important precursor to acid rain and may affect both terrestrial and aquatic ecosystems. Atmospheric deposition of nitrogen leads to excess nutrient enrichment problems (“eutrophication”) in the Chesapeake Bay and several nationally important estuaries along the East and Gulf Coasts. Eutrophication can produce multiple adverse effects on

water quality and the aquatic environment, including increased algal blooms, excessive phytoplankton growth, and low or no dissolved oxygen in bottom waters. Eutrophication also reduces sunlight, causing losses in submerged aquatic vegetation critical for healthy estuarine ecosystems. Deposition of nitrogen-containing compounds also affects terrestrial ecosystems. Nitrogen fertilization can alter growth patterns and change the balance of species in an ecosystem. In extreme cases, this process can result in nitrogen saturation when additions of nitrogen to soil over time exceed the capacity of plants and microorganisms to utilize and retain the nitrogen.

Elevated levels of nitrates in drinking water pose significant health risks, especially to infants. Studies have shown that a substantial rise in nitrogen levels in surface waters are highly correlated with human-generated inputs of nitrogen in those watersheds.<sup>6</sup> These nitrogen inputs are dominated by fertilizers and atmospheric deposition.

Nitrogen dioxide and airborne nitrate also contribute to pollutant haze, which impairs visibility and can reduce residential property values and tourism revenues. Section II.D. further describes information about visibility impairment and regional haze.

### **B. Particulate Matter**

Particulate matter (PM) is the general term for the mixture of solid particles and liquid droplets found in the air. Particulate matter includes dust, dirt, soot, smoke, and liquid droplets that are directly emitted into the air from natural sources (such as windblown dust and fires) and manmade sources (such as motor vehicles, construction sites, factories, and driving on unpaved roads). Secondary PM is formed in the atmosphere through a number of physical and chemical processes that transform gases such as sulfur dioxide, NO<sub>x</sub>, and VOC into particles.

Particulate matter is distinguished between larger or "coarse" particles (larger than 2.5 micrometers) and smaller or "fine" particles (smaller than 2.5 micrometers). The characteristics, sources, and potential health effects of coarse and fine particles are very different. Coarse particles primarily come from natural sources, such as windblown dust and sea salt. They remain in the atmosphere a relatively short period of time. Fine particles primarily consist of secondary particles formed by gaseous emissions and often come from human sources, such as industrial and residential combustion, vehicle exhaust, and agriculture (including silvicultural prescribed burning). Fine PM consists primarily of sulfate-based particles (produced from sulfur oxides (SO<sub>x</sub>)), nitrate-based particles (produced from NO<sub>x</sub>), and carbon-based particles emitted directly from combustion processes and created through transformation of VOC emissions. Particles directly emitted from motor vehicles, and those formed by the transformation of motor vehicle gaseous emissions, tend to be in the fine particle range.

The formation and fate of secondary PM involves complex processes which are sensitive

to sunlight, temperature, humidity, and other reactants. SO<sub>x</sub>, NO<sub>x</sub>, and VOC emissions are photochemically oxidized and react with water vapor to form sulfuric and nitric acids.<sup>b</sup> Sulfuric acid reacts with ammonia to form mostly ammonium sulfate and some ammonium bisulfate, while nitric acid reacts with ammonia to form ammonium nitrate. Ammonia gas is emitted from biogenic sources and biomass burning, both natural and anthropogenic. If ammonia is in limited supply, it will react to form sulfate rather than nitrate since sulfuric acid has a higher chemical affinity for ammonia than does nitric acid. Furthermore, ammonium nitrate reacts with ammonia and nitric acid in an equilibrium reaction, so nitric acid removal processes such as dry deposition will also lower the concentration of nitrate PM.

As a result, a much higher fraction of SO<sub>x</sub> is converted to PM than is the case for NO<sub>x</sub>. Conversion rates vary depending on local meteorology and the amount of ammonia, NO<sub>x</sub>, and SO<sub>x</sub> in the local atmosphere. However, mobile sources reasonably can be estimated to contribute to ambient secondary sulfate and nitrate in proportion to their contribution to total NO<sub>x</sub> and SO<sub>x</sub> emissions in a given area geographically.

Mobile sources are significant producers of carbonaceous PM, which consists largely of elemental carbon directly emitted by diesel vehicles and poorly maintained gasoline vehicles. Secondary carbonaceous PM results when VOCs or their photochemical reaction products adsorb to existing particles.

In the eastern U.S., based on limited monitoring data, sulfate is the largest single component of fine PM, closely followed by carbonaceous PM. Nitrate is the third-largest component of fine PM, accounting for roughly 10 percent of the total. Most of the rest is soil dust. In the West, again based on limited monitoring data, carbonaceous PM is generally the largest fraction of fine PM. Sulfate forms a smaller fraction of fine PM than in the East, probably because SO<sub>x</sub> emissions are lower. Sulfate still comprises a larger fraction of the total than nitrate, however, except in parts of California. Soil dust is a more important component of fine PM in the West than in the East, but is still smaller than nitrate in most places. Throughout the U.S., rural areas have lower fine PM levels than urban areas.

### **1. Health and Welfare Effects of Particulate Matter**

Scientific studies have linked particulate matter (alone or in combination with other air pollutants) with a series of health effects.<sup>7</sup> Coarse particles can accumulate in the respiratory system and aggravate health problems such as asthma. Fine particles penetrate deeply into the lungs and are more likely than coarse particles to contribute to a number of the health effects. These health effects include premature death and increased hospital admissions and emergency

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<sup>b</sup>Sulfuric acid is a particulate, while nitric acid is a gas at ambient conditions.

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room visits, increased respiratory symptoms and disease, decreased lung function, and alterations in lung tissue and structure and in respiratory tract defense mechanisms. Children, the elderly, and people with cardiopulmonary disease, such as asthma, are most at risk from these health effects. Chapter III contains a discussion of the toxic health effects from particulate matter in diesel fuel exhaust.

Particulate matter also causes a number of adverse effects on the environment. Fine particulate matter is the major cause of reduced visibility in parts of the U.S., including many of our national parks and wilderness areas. (Section II.D. further describes visibility impairment and regional haze). Other environmental impacts occur when particles deposit onto soil, plants, water, or materials. For example, particles containing nitrogen and sulfur that deposit onto land or water bodies may change the nutrient balance and acidity of those environments, leading to changes in species composition and buffering capacity.

Particles that are deposited directly onto leaves of plants can, depending on their chemical composition, corrode leaf surfaces or interfere with plant metabolism. When deposited in sufficient quantities, such as near unpaved roads, tilled fields, or quarries, particles block sunlight from reaching the leaves, stressing or killing the plant. Finally, particulate matter causes soiling and erosion damage to materials, including culturally important objects, such as carved monuments and statues.

### **C. Carbon Monoxide**

Carbon monoxide (CO) is a colorless, odorless gas produced through the incomplete combustion of carbon-based fuels. Carbon monoxide enters the bloodstream through the lungs and reduces the delivery of oxygen to the body's organs and tissues. The health threat from CO is most serious for those who suffer from cardiovascular disease, particularly those with angina or peripheral vascular disease. Healthy individuals also are affected, but only at higher CO levels. Exposure to elevated CO levels is associated with impairment of visual perception, work capacity, manual dexterity, learning ability and performance of complex tasks.

Several recent epidemiological studies have shown a link between CO and premature mortality and morbidity (including angina, congestive heart failure, and other cardiovascular diseases). EPA currently is in the process of reviewing these studies as part of the CO Criteria Document process.

Since 1979, the number of areas in the nation violating the CO NAAQS has decreased by a factor of almost ten, from 48 areas in 1979 to five areas (covering seven counties) in 1995 and 1996. In 1997, three counties, with a total population of nine million people, failed to meet the CO standard.

In addition to the substantial decrease in the number of areas where the NAAQS is exceeded, the severity of the exceedances also has decreased significantly. Nationally, CO concentrations decreased 38 percent during the past 10 years.<sup>c</sup> From 1979 to 1996, the measured atmospheric concentrations of CO during an exceedance decreased from 20-25 ppm at the beginning of the period to 10-12 ppm at the end of the period. Expressed as a multiple of the standard, atmospheric concentration of CO during an exceedance was two to almost three times the standard in 1979. By 1996, the CO levels present during an exceedance decreased to 10-30 percent over the nine ppm standard.

Unlike the case with ozone and PM, EPA has not made any recent comprehensive projections of future ambient CO levels and attainment and maintenance of the CO NAAQS. However, section 202(j) of the CAA requires a separate study of the need for more stringent CO standards. EPA is currently conducting this study.

### **D. Visibility and Regional Haze**

Visibility impairment is the haze that obscures what we see, and is caused by the presence of tiny particles in the air. These particles cause light to be scattered or absorbed, thereby reducing visibility. Visibility impairment, also called regional haze, is a complex problem that relates to several pollutants. Visibility in our national parks and monuments, and many urban areas of the country, continues to be obscured by regional and local haze.

The principle cause of visibility impairment is fine particles, primarily sulfates, but also nitrates, organics, and elemental carbon and crustal matter. Particles between 0.1 and one micrometers in size are most effective at scattering light, in addition to being of greatest concern for human health. Of the pollutant gases, only NO<sub>2</sub> absorbs significant amounts of light; it is partly responsible for the brownish cast of polluted skies. However, it is responsible for less than ten percent of visibility reduction.

In the eastern U.S., reduced visibility is mainly attributable to secondary particles, particularly those less than a few micrometers in diameter. Based on data collected by the Interagency Monitoring of Protected Visual Environments (IMPROVE) network for visibility monitoring, sulfate particles account for about 50-70 percent of annual average light extinction in eastern locations. Sulfate plays a particularly significant role in the humid summer months, most notably in the Appalachian, northeast, and mid-south regions. Nitrates, organic carbon, and elemental carbon each account for between 10–15 percent of total light extinction in most eastern locations. Rural areas in the eastern U.S. generally have higher levels of impairment than most

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<sup>c</sup>This value of the CO concentration decrease is measured by the composite average of the annual second highest 8-hour concentration.

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remote sites in the western U.S., generally due to the eastern U.S.'s higher levels of man-made pollution, higher estimated background levels of fine particles, and higher average relative humidity levels.

The relative contribution of individual pollutants to visibility impairment vary geographically. While secondary particles still dominate in the West, direct particulate emissions from sources such as woodsmoke contribute a larger percentage of the total particulate load than in the East. In the rural western U.S., sulfates also play a significant role, accounting for about 25–40 percent of total light extinction in most regions. In some areas, such as the Cascades region of Oregon, sulfates account for over 50 percent of annual average light extinction. Organic carbon typically is responsible for 15–35 percent of total light extinction in the rural western U.S. and elemental carbon (absorption) accounts for about 15–25 percent, so the total carbonaceous contribution is between 30 and 60 percent. Soil dust (coarse PM) accounts for about 10–20 percent. Nitrates typically account for less than 10 percent of visibility impairment.<sup>8</sup>

The CAA requires EPA to protect visibility, or visual air quality, through a number of programs. These programs include the national visibility program under sections 169a and 169b of the Act, the Prevention of Significant Deterioration program for the review of potential impacts from new and modified sources, and the secondary NAAQS for PM<sub>10</sub> and PM<sub>2.5</sub>. The national visibility program established in 1980 requires the protection of visibility in 156 mandatory Federal Class I areas across the country (primarily national parks and wilderness areas). The CAA established as a national visibility goal, “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Federal class I areas in which impairment results from manmade air pollution.” The Act also calls for state programs to make “reasonable progress” toward the national goal. In July 1997, EPA proposed a program to address regional haze in the nation’s most treasured national parks and wilderness areas (see 62 FR 41137, July 31, 1997).

Since mobile sources contribute to visibility-reducing PM, control programs that reduce the mobile source emissions of direct and indirect PM will have the effect of improving visibility. Western Governors, in commenting on the Regional Haze Rule and on protecting the 16 Class I areas on the Colorado Plateau, stated that, “...the federal government must do its part in regulating emissions from mobile sources that contribute to regional haze in these areas...” and called on EPA to make a “binding commitment to fully consider the Commission’s recommendations related to the ... federal national mobile source emissions control strategies”, including Tier 2 vehicle emissions standards.<sup>9</sup> The Grand Canyon Visibility Transport Commission’s report found that reducing total mobile source emissions is an essential part of any program to protect visibility in the Western U.S.<sup>10</sup> The Commission identifies mobile source pollutants of concern as VOC, NO<sub>x</sub>, and elemental and organic carbon.



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### Chapter II References:

1. U.S. EPA, 1996, Review of National Ambient Air Quality Standards for Ozone, Assessment of Scientific and Technical Information, OAQPS Staff Paper, EPA-452/R-96-007.
2. U.S. EPA, 1996, Air Quality Criteria for Ozone and Related Photochemical Oxidants, EPA/600/P-93/004aF.
3. U.S. EPA, 1997, Regulatory Impact Analysis for the Ozone NAAQS, Appendix J, "Assessment and Synthesis of Available Epidemiological Evidence of Mortality Associated with Ambient Ozone from Daily Time-series Analyses".
4. U.S. EPA, 1995, Review of National Ambient Air Quality Standards for Nitrogen Dioxide, Assessment of Scientific and Technical Information, OAQPS Staff Paper, EPA-452/R-95-005
5. U.S.EPA, 1993, Air Quality Criteria for Oxides of Nitrogen, EPA/600/8-91/049aF.
6. Vitousek, Pert M., John Aber, Robert W. Howarth, Gene E. Likens, et al. 1997. Human Alteration of the Global Nitrogen Cycle: Causes and Consequences. *Issues in Ecology*. Published by Ecological Society of America, Number 1, Spring 1997.
7. U.S. EPA, 1996, Air Quality Criteria for Particulate Matter, EPA/600/P-95/001aF.
8. "National Air Quality and Emissions Trends Report, 1996", EPA Document Number 454/R-97-013.
9. Letter from Governor Michael Leavitt of Utah, on behalf of the Western Governors' Association, to EPA Administrator Carol Browner, dated June 29, 1998.
10. "Report of the Grand Canyon Visibility Transport Commission to the United States Environmental Protection Agency", June 1996.